Seasonal and Topographic Variation in Net Primary Productivity in the Madrean Sky Islands

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CZO CRITICAL ZONE OBSERVATORIES U.S. NSF NATIONAL PROGRAM

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Introduction

Western US forests remain an uncertain sink for carbon. Semi-arid forests in particular have the potential to uptake and store carbon in large amounts. Addressing and understanding controls on biogeochemical cycling in these forests will allow researchers to model ecosystem productivity with greater detail.

Measurements of ecosystem productivity across the globe quite often rely on eddy covariance tower data due to the high temporal resolution and autonomous instrument setup. These NEE values are very useful at quantifying the movement of C on a broad scale, but only capture a snapshot of the landscape. Small-scale processes that influence productivity cannot be discerned from tower data, but play a role nonetheless.

We have noticed that differences in topographic aspect on Mt. Bigelow, in southern Arizona, experience different environmental conditions throughout the year

Does the difference in energy inputs on opposing N and S aspects lead to differences in primary productivity in a semi-arid forest?

Under similar solar conditions, is there a distinct difference in primary productivity between wet and dry periods?

Methods

Above:
Left – Clipping samples from the middle of the canopy for three species. This was done before every measurement.
Middle – Water potential measurements taken at the site. Both pre-dawn and midday water potential measurements were taken for each individual sample.
Right – Photosynthesis measurements using the LI-6400. Ambient conditions were simulated for each measurement day.

To address the question of whether aspect controls NPP, we sampled trees on opposing north (N) and south (S) aspects in a zero-order basin (ZOB). Measurement periods were selected based on seasons and further divided by distinguishing characteristics (eg: dry summer vs. monsoon summer) in 2016.

Measurements were taken from trees in a medium-aged stand (Ponderosa Pine, Douglas Fir, Southwestern White Pine) on top of Mt. Bigelow in the Catalina Mountains, part of the Coronado National Forest.

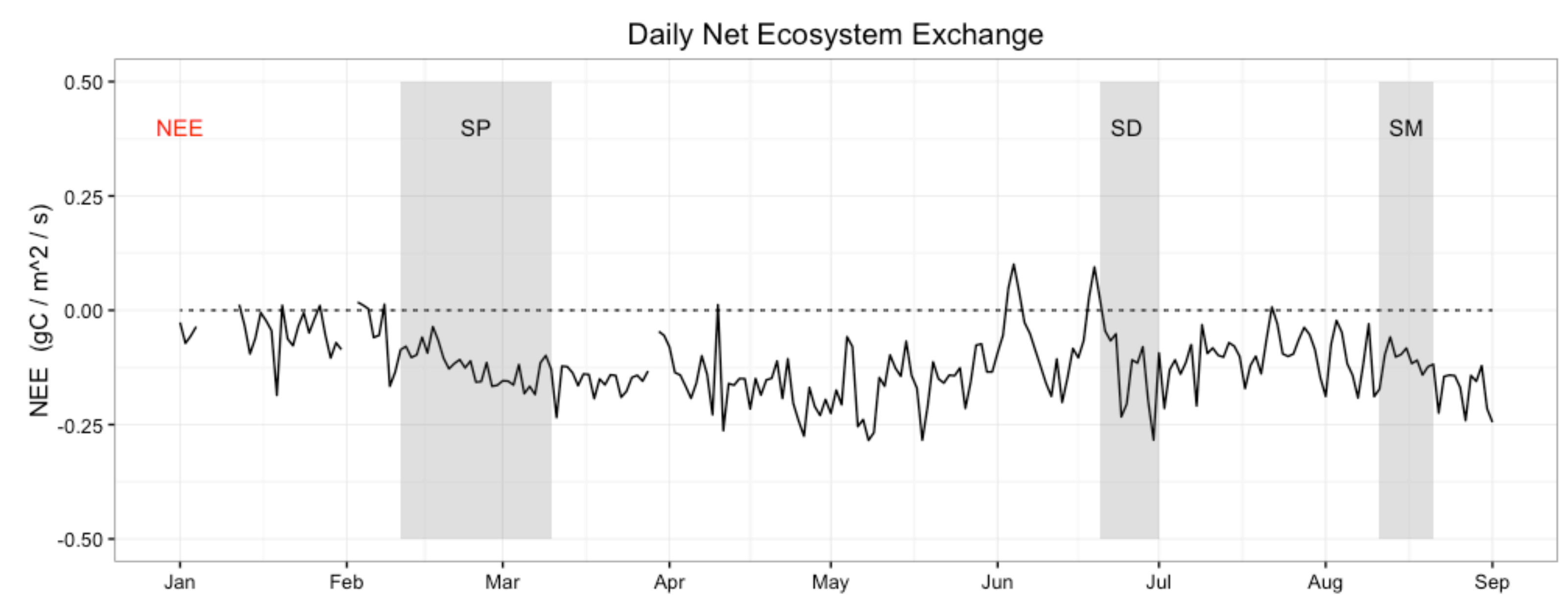
Time series data (plots 1-5) were from sensors mounted on both aspects or on the eddy covariance tower installed on the west edge of the ZOB.

A measurement day consisted of both nighttime and daytime sampling:

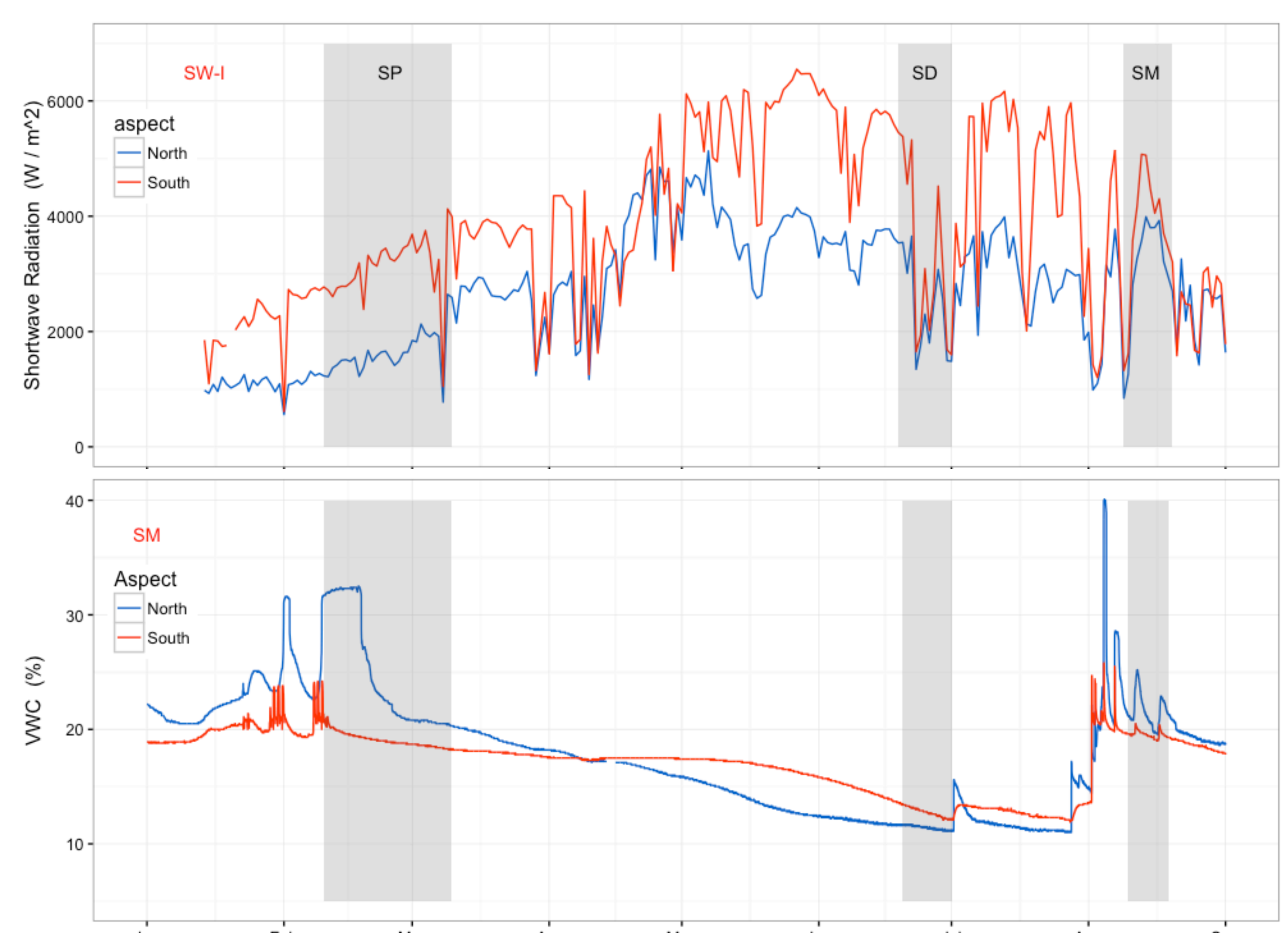
<u>Nighttime</u>
- Clipping samples before sunrise
- Measuring pre-dawn water potential with a Scholander pressure chamber

<u>Daytime</u>
- Clipping samples mid-morning
- Measuring midday water potential with a Scholander pressure chamber
- Placing remaining clippings in a water bucket to re-introduce hydraulic connectivity
- Measuring photosynthesis with an LI-6400 gas exchange chamber

VPD: Vapor pressure deficit is calculated as a function of temperature and humidity. VPD increases until mid-summer, when the monsoon storms drop temperatures slightly and increase moisture in the air.
PPT: Total precipitation (summed daily). Very little rain falls during spring and early summer, but large precipitation pulses occur after July 1st when the monsoon season generally begins.



Net Ecosystem exchange is plotted here for 2016. This is a measurement of C exchange between the forest and the atmosphere. This one value is applied to the entire landscape, though it does not necessarily reflect each individual tree within that landscape. Unmet assumptions of this method drive the research questions addressed here.



SW-I: A daily sum of incoming shortwave radiation (48 points) was calculated from radiation sensors on both aspects. The sum displays an exaggerated perspective of the relative insolation on the N (lower) vs S (higher) aspects.
SM: The difference in radiation received at the soil surface is evident in the soil moisture data shown here. While the S aspect is bombarded with solar radiation relative to the N aspect, it experiences sooner and more rapid snowmelt that is characterized primarily by runoff and evaporation. The N aspect experiences later and slower snowmelt, which allows more water to infiltrate into the soil. Soil moisture here represents 50cm depth.

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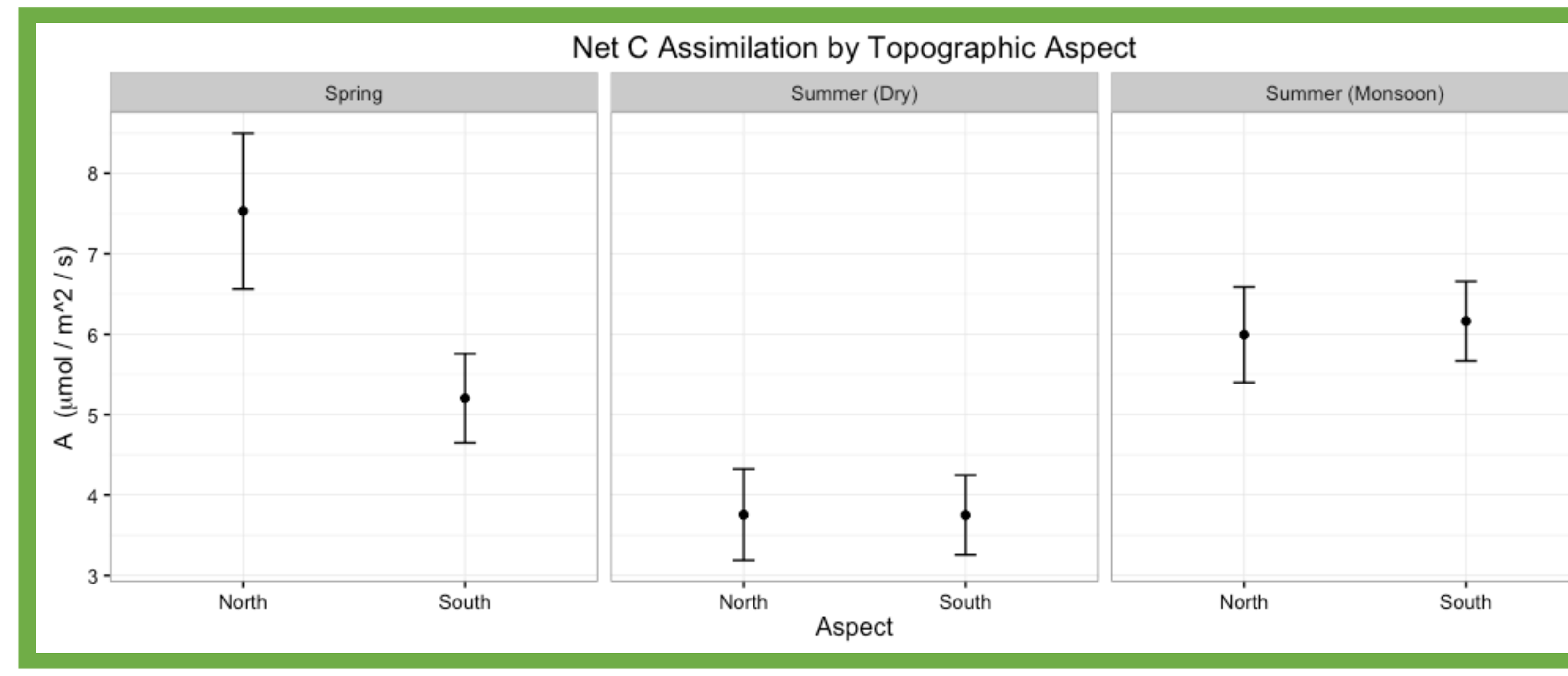
Results/Discussion



Results from the study. In the spring, higher rates of carbon assimilation are measured from tress on the N aspect relative to those on the S aspect. This follows the hypothesis that higher insolation on the S aspect during the spring equinox dries out soils quicker, resulting in less water available for vegetation. Following this, the summer dry and summer monsoon periods see very little difference between aspects; both of these periods follow soon after the summer solstice, so the sun is more directly overhead.

Does the difference in energy inputs on opposing N and S aspects lead to differences in primary productivity in a semi-arid forest?

Yes – Initial results indicate that there are differences between photosynthetic rates on opposing N and S aspects. Photosynthesis is statistically lower on the S aspect ($p<0.05$) during spring. The S aspect receives higher rates of insolation compared to the N aspect. In the spring, this may be a result of more direct sunlight on the S aspect, as well as a denser canopy and more shading on the N aspect. As a result, snowmelt on the S aspect occurs earlier in the spring and has a higher ratio of runoff to infiltration.

No – During the summer, when the sun is more directly overhead, differences due to aspect disappear.

Under similar solar conditions, is there a distinct difference in primary productivity between wet and dry periods?

Yes – Neither summer measurement period (dry or monsoon) shows a statistical difference in photosynthetic rates between aspects. However, when comparing all photosynthetic rates during the dry period to those in the wet period, there is a very significant statistical difference ($p<0.001$). A linear correlation of photosynthesis to pre-dawn water potential shows an extremely weak, positive relationship (R^2 = 0.03). This is an indication that these trees are not water-stressed, yet they continue to respond to greater soil moisture.

Conclusions

Ecosystem activity and health are quite often studied through the lens of a flux tower. This perspective is important to spatio-temporal patterns on a global scale and tells us a great deal. **But, this method requires assumptions that are rarely met, and these same methods may not be applicable to describe landscape-level interactions.**

The divergence in primary productivity between opposing aspects during the growing season highlights that a single NEE value cannot fully capture the heterogeneity in a forest landscape, especially one with variable topography and multiple species.

It is crucial that researchers build a detailed understanding of ecosystem processes and mechanisms, and implement these findings in models that reconstruct interactions and feedbacks in these complex ecosystems.

Acknowledgements: The Barron-Gafford Lab has been a tremendous help in designing and implementing the research done for this project. Financial support of data collection and management came from two NSF grants (award numbers: 1417101, 1331408). Some data is provided by the NSF Critical Zone Observatories program.